Rapid Appraisal Process (RAP) and Benchmarking
Explanation and Tools

originally funded by:

Food and Agriculture Organization of the United Nations
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Irrigation Institutions Window
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September 2001
rev. December 2001
rev. October 2002 for World Bank Irrigation Institutions Window

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This Document

This WORD® document [Rapid Appraisal Process (RAP) and Benchmarking] provides an explanation of the Rapid Appraisal Process (RAP), as well as a brief explanation of Benchmarking and the data that must be collected for both endeavors. This document also provides an explanation the EXCEL® documents that are used by persons during the RAP. An EXCEL spreadsheet (with 12 internal worksheets) is provided twice:

1. Rapid Appraisal and Benchmarking BLANK.xls
2. Rapid Appraisal and Benchmarking EXAMPLE.xls

As the names suggest, the EXAMPLE has data in it so that users can examine an example before entering data in a blank spreadsheet.

This documentation and the 2 spreadsheet documents can be downloaded from the Cal Poly ITRC web page:

http://www.itrc.org/papers/papersindex.html

Preparation for Field Work

Prior to visiting an irrigation project, one should send the following EXCEL worksheets to the project:

1. Input –Year1
5. Project Office Questions
6. WUA (up to and including row 94; and rows 217-225. Intermediate rows have questions that must be answered by the evaluator during a visit.

All of the questions must be clearly understood by the evaluator before visiting a project, because many of the questions will not be answered during a formal interview process. Rather, the majority of questions will be answered based on observations made during a visit to the main canal, secondary and tertiary canals, water users, offices, and fields.

Background

The **Rapid Appraisal Process (RAP)** allows qualified personnel to systematically and quickly determine key indicators of irrigation projects. The RAP can generally be completed with 2 weeks or less of field and office work – assuming that some readily available data on the project have been organized by project authorities in advance of the RAP.

Key performance indicators from RAP help to organize perceptions and facts, thereby facilitating informed decisions regarding

- The potential for water conservation within a project
- Specific weakness in project operation, management, resources, and hardware
- Specific modernization actions that can be taken to improve project performance.

A parallel activity to the RAP is called **Benchmarking**. As defined in preliminary IPTRID (International Program for Technology and Research in Irrigation and Drainage) documents, benchmarking is a systematic process for securing continual improvement through comparison with relevant and achievable internal or external norms and standards. The overall aim of benchmarking is to improve the performance of an organization as measured against its mission and objectives. Benchmarking implies comparison – either internally with previous performance and desired future targets, or externally against similar organizations, or organizations performing similar functions. Benchmarking is in use in both the public and private sector.

Benchmarking incorporates various indicators, many of which are developed from the RAP. Both the RAP and the IPTRID benchmarking activity are still evolving, so the indicators found in this RAP document will not always be identical to those in IPTRID documents. This document has been revised to reflect current efforts by the World Bank to combine the processes.

The Rapid Appraisal Process (RAP) of irrigation projects was introduced in a joint FAO/IPTRID/World Bank publication entitled *Water Reports 19 (FAO) – Modern Water*

Control and Management Practices in Irrigation – Impact on Performance (Burt and Styles, 1999). That publication provides an explanation of the RAP and also gives RAP results from 16 international irrigation projects. Readers are strongly encouraged to obtain Water Reports 19 directly from FAO (http://www.fao.org/icatalog/inter-e.htm) as further background to RAP.

A document that discusses philosophy of operation and design of irrigation projects is
World Bank Technical Paper No. 246 – Modern Water Control in Irrigation
(Plusquellec, Burt, and Wolter, 1994)
Available from:
Distribution Unit
Office of the Publisher
The World Bank
1818 H Street, N.W.
Washington, D.C. 20433 USA

The Rapid Appraisal Process (RAP)

The RAP can be described as follows

> The Rapid Appraisal Process (RAP) for irrigation projects is a 1-2 week process of collection and analysis of data both in the office and in the field. The process examines external inputs such as water supplies, and outputs such as water destinations (ET, surface runoff, etc.). It provides a systematic examination of the hardware and processes used to convey and distribute water internally to all levels within the project (from the source to the fields). External indicators and internal indicators are developed to provide (i) a baseline of information for comparison against future performance after modernization, (ii) benchmarking for comparison against other irrigation projects, and (iii) a basis for making specific recommendations for modernization and improvement of water delivery service.

The Rapid Appraisal Process (RAP) has only recently been used for diagnosis of international irrigation projects, although variations of the RAP presented here have been used since 1989 by the Irrigation Training and Research Center (ITRC) at California Polytechnic State University on dozens of irrigation modernization projects throughout the western U.S.A.

Traditional diagnostic procedures and research tend to examine *portions* of a project, whether they are the development of water user associations (WUAs) or the fluctuation of flow rates in a single canal lateral. Those research projects typically require the collection of substantial field data over extended periods of time.

The time and budgetary requirements of such standard research procedures are significant - Kloezen and Garcés-Restrepo (1998) state that "three engineers worked full-time for more than a year to collect primary data and make measurements to apply process indicators at the level of selected canals and fields" for just one project. Furthermore, they state that "In addition, the work in Salvatierra was supported by an M.Sc. student...In addition, much time was spent on visiting the selected field and taking several flow measurements per field, per irrigation... Five more months were spent on entering, cleaning, and processing data." Clearly, although time-consuming research can provide valuable information about irrigation, decisions for modernization improvements must be made more quickly and must be comprehensive.

An essential ingredient of the successful application of these RAPs is adequate training of the evaluators. Experience has shown that successful RAP programs require (i) evaluators with prior training in irrigation, (ii) specific training in the RAP techniques, and (iii) follow-up support and critique when the evaluators begin their field work.

A RAP will be unsuccessful if the EXCEL files are merely mailed to local irrigation projects to be filled out. Evaluators must understand the logic behind all the questions, and must learn how to go beyond the obvious when obtaining data. Ideally, if two qualified persons complete a RAP on a single irrigation project, the indicators that are computed by both persons will be very similar.

Typical baseline data for external indicators (such as water balances and irrigation efficiency) are either readily available or they are not. Individual irrigation projects have differences in the ease of access to typical baseline data on the command area, weather, water supply, etc. In some projects the data can be gathered in a day; in others it may take weeks. Usually the delays in data organization are due to simply finding the time to pull the data out of files and organizing it. If the data does not already exist, spending an additional 3 months on the site will not create the data.

A quick and focused examination of irrigation projects can give a reasonably accurate and pragmatic description of the status of the project and the processes and hardware that influence that status. This allows for the identification of the major actions that can be taken quickly to improve water delivery service – especially if the RAP is conducted in cooperation with the local irrigation authorities.

The question of what is "reasonably accurate" in data collection and computations can always be debated. Confidence intervals should be assigned to most water balance data – reflecting the reality that we always have uncertainties in our data and computation techniques. In irrigation matters, one is typically concerned about 5-10% accuracy, not 0.5-1% accuracy ranges (Burt et al., 1997). The problems one encounters in irrigation projects are typically so gross and obvious (to the properly trained eye) that it is unnecessary to strive for extreme accuracy when one wants to diagnose an irrigation project. Furthermore, (i) projects typically have such unique sets of characteristics that the results from a very detailed study of just a few items on one project may have limited transferability to other projects, and (ii) even with very sophisticated and detailed research, it is difficult to achieve better than about 5-10% accuracy on some key values such as crop evapotranspiration of irrigation water.

For the RAP, one begins with a prior request for information that can be assembled by the irrigation project authorities – information such as cropped areas, flow rates into the project, weather data, budgets, and staffing. Upon arriving at the project, that data is organized and project managers are interviewed regarding missing information and their perceptions of how the project functions. One then travels down and through the canal network, talking to operators and farmers, and observing and recording the methods and hardware that are used for water control. Through this systematic diagnosis of the project, many aspects of engineering and operation become very apparent.

Economic data are major components for some indicators that have been proposed by others. The experiences of the author have shown that a RAP is not suitable for the collection of some economic data. Data such as the overall cost of a project in today's dollars, per capita income, and the size of typical farm management units were not readily available in most projects that are described in FAO Water Report 19.

In summary, if properly executed with qualified personnel, the RAP can quickly provide valuable insight into many aspects of irrigation project design and operations. Furthermore, its structure provides a systematic project review that enables an evaluator to provide pragmatic recommendations for improvement.

Some of the data that is collected during a RAP is also useful in quantifying various Benchmark indicators that have been established by IPTRID. Most of the IPTRID Benchmark indicators fall into the category of "external indicators", whereas RAP indicators include both "external" and "internal" indicators. As discussed in the next sections, "internal" indicators are necessary to understand the processes used within an irrigation project, the level of water delivery service throughout a project, and they also help an evaluator to formulate an action plan that will eventually result in an improvement of external indicators. External indicators and traditional Benchmarking indicators provide little or no guidance as to what must be done to accomplish improvement. Rather, they only indicate that things should be improved.

External Indicators for Water Sources and Water Destinations

External Indicators. External indicators for irrigation projects are ratios or percentages that generally have forms such as:

$$\frac{\text{Water Required}}{\text{Total Water Available}}$$

or

$$\frac{\text{Crop Yield}}{\text{Irrigation Water Delivered to the Fields}}$$

The Benchmarking indicators of IPTRID fall into the category of "external indicators", and the RAP also generates a long list of external indicators.

The common attribute of external indicators is that they examine inputs and outputs for a project. External indicators are expressions of various forms of efficiency, whether the efficiency is related to budgets, water, or crop yields. But even more than that, they only require knowledge of inputs and outputs to the project. By themselves, external indicators do not provide any insight into what must be done to improve performance or efficiency. The identification of what actions must be taken to improve these external indicators comes from an examination of internal indicators, which examine the processes and hardware used within the project.

However, external indicators do establish key values – such as whether or not it might be possible to conserve water (without defining how that might be accomplished). As such, low values of external indicators often provide the justification for modernization of projects – with the anticipation that modernization or intervention will improve the values of those external indicators.

The RAP external indicators focus on items of a typical water balance. As such, values such as crop evapotranspiration, effective precipitation, and water supplies must be obtained. The primary purpose of the first three worksheets in the EXCEL spreadsheet is to estimate water-related external indicators.

Confidence Intervals. A certain amount of error or uncertainty is inherent in all measurement or estimation processes. Therefore, we do not actually know the true or correct values for the water volumes needed to calculate terms such as "Irrigation Efficiency". Estimates must be made of the component volumes, based on measurements or calculations.

In reports that provide estimates of terms such as crop yield and water balance ratios such as "Irrigation Efficiency" and "Relative Water Supply", the uncertainties associated with those estimates should be acknowledged and quantified. Otherwise, planners may not know if the true value of a stated 70% efficiency lies between 65% and 75%, or between 50% and 90%.

One method of expressing the uncertainty in a single-valued estimate is to specify the confidence interval (CI) for that estimate. If it is believed that a reasonable evaluation of data indicates that the correct value lies within 5 units of 70, then it should be stated that the quantity equals 70±5. More specifically, the essence of a confidence interval should be illustrated as follows when discussing an estimated quantity:

> "The investigators are 95% confident that their estimate of the irrigated area in the project is within ±7% of 500,000 ha (between 465,000 ha and 535,000 ha)."

Statistically a CI is related to the coefficient of variation (cv), where

$$cv = \frac{\text{mean}}{\text{standard deviation}} \qquad \text{(note that the "cv" has no units)}$$

and

$$CI = \pm 2 \times cv,$$

where the CI is expressed as a fraction ($\frac{\%}{100}$) of the estimated value. Stated differently, if the CI is declared to be 0.10, this means that the ±2 standard deviations cover a range of ± 10% of the stated value.

Assuming a normal distribution of data, approximately 68% of the time the true value is found within plus or minus one standard deviation of the estimated value. Likewise, approximately 95% of the time (from which comes the "we are 95% confident" statement), the true value is found within plus or minus 2 standard deviations of the estimated value.

One could logically ask, "How confident are you of the CI that has been selected?" The answer for a RAP is that "The CI is not precise, but it nevertheless gives a good idea of the evaluator's sense for the accuracy of various values." Certainly, it is much better to provide a relative indication of the uncertainty in a value than it is to ignore the uncertainty and have people treat estimates as if they are absolute values.

In the RAP, the evaluator is asked to provide CI estimates for various data quantities. Those CI estimates are manually entered into blank cells of the fourth worksheet (4. External Indicators). The spreadsheet then automatically calculates CI estimates for indicators that use those data.

The most common convention for computing the CI of a computed value (result) is as follows:

1. If two independently estimated quantities are added, the CIs are related by

$$CI_r = \frac{\sqrt{m_1^2 CI_1^2 + m_2^2 CI_2^2}}{m_1 + m_2}$$

where

CI_r = CI of the result
CI_1 = CI of the first quantity added to form the result
CI_2 = CI of the second quantity added to form the result
m_1 = estimated value of the first quantity
m_2 = estimated value of the second quantity

2. If two independently estimated quantities are multiplied together, the CIs are related by

$$CI_r = \sqrt{CI_1^2 + CI_2^2 + \frac{CI_1^2 CI_2^2}{4}}$$

One could correctly point out that a rigorous estimate of CIs would require assigning CI values to each of the original data in the first three “INPUT” worksheets of the EXCEL spreadsheet. However, for a typical RAP, it is not worthwhile striving for more precision than can obtained by inserting CI estimates in the “Indicator Summary” worksheet. For convenience of the evaluator, the “Indicator Summary” worksheet automatically computes the CI_r for some pertinent quantities, utilizing various CI values that are provided by the evaluator.

Internal Processes and Internal Indicators

Broad goals of modernization are to achieve improved irrigation efficiency (an external indicator), better crop yields (another external indicator that is not used here), less canal damage from uncontrolled water levels, more efficient labor, improved social harmony, and an improved environment as accomplished by less diversions or better quality return flows. In general, these goals can only be achieved by paying attention to internal details. The specific details addressed by RAP are improving water control throughout the project, and improving the water delivery service to the users

Therefore, the EXCEL worksheets 5 – 11 have the following purposes:
1. Identify the key factors related to water control throughout a project.
2. Define the level of water delivery service provided to the users.
3. Examine specific hardware and management techniques and processes used in the control and distribution of water.

Many of these items are described in the form of "internal indicators", with assigned values of 0-4 (0 indicating least desirable, and 4 denoting the most desirable).

A summary of the internal indicators is found in worksheet 12. Most of the internal indicators have subcomponents, called "sub-indicators". At the end of the spreadsheet, each of the sub-indicators is assigned a "weighting factor".

As an example of the usage of internal indicators, Primary Indicator I-1 is used to characterize the actual water delivery service to individual ownership units. Primary Indicator I-1 has 4 sub-indicators:

I-1A. Measurement of volumes to the field
I-1B. Flexibility to the field
I-1C. Reliability to the field
I-1D. Apparent equity.

Each of the Sub-Indicators (e.g., No. I-1A) has a maximum potential value of 4.0 (best), and a minimum possible value of 0.0 (worst).

The value for each Primary Indicator (e.g., No. I-1) is computed automatically in the "Internal Indicators" worksheet by:

1. Applying a relative weighting factor to each sub-indicator value. The weighting factors are only relative to each other within the indicator group; one group may have a maximum value of 4, whereas another group may have a maximum value of 2. The only factor of importance is the relative weighting factors of the sub-indicators within a group.
2. Summing the weighted sub-indicator values.
3. Adjusting the final value based on a possible scale of 0-4 (4 indicating the most positive conditions).

Primary Indicator I-1 Information.

No.	Primary Indicator	Sub-Indicator	Ranking Criteria	Wt
I-1	Actual water delivery service to individual ownership units (e.g., field or farm)			
I-1A		Measurement of volumes to the individual units (0-4)	4 – Excellent measurement and control devices, properly operated and recorded. 3 – Reasonable measurement and control devices, average operation. 2 – Useful but poor measurement of volumes and flow rates. 1 – Reasonable measurement of flow rates, but not of volumes. 0 – No measurement of volumes or flows.	1
I-1B		Flexibility to the individual units (0-4)	4 – Unlimited frequency, rate, and duration, but arranged by users within a few days. 3 – Fixed frequency, rate, or duration, but arranged. 2 – Dictated rotation, but it approximately matches the crop needs. 1 – Rotation deliveries, but on a somewhat uncertain schedule. 0 – No established rules.	2
I-1C		Reliability to the individual units (0-4)	4 – Water always arrives with the frequency, rate, and duration promised. Volume is known. 3 – Very reliable in rate and duration, but occasionally there are a few days of delay. Volume is known. 2 – Water arrives about when it is needed and in the correct amounts. Volume is unknown. 1 – Volume is unknown, and deliveries are fairly unreliable, but less than 50% of the time. 0 – Unreliable frequency, rate, duration, more than 50% of the time, and volume delivered is unknown.	4
I-1D		Apparent equity to individual units (0-4)	4 – All fields throughout the project and within tertiary units receive the same type of water delivery service. 3 – Areas of the project receive the same amounts of water, but within an area the service is somewhat inequitable. 2 – Areas of the project receive somewhat different amounts (unintentionally), but within an area it is equitable. 1 – There are medium inequities both between areas and within areas. 0 – There are differences of more than 50% throughout the project on a fairly widespread basis.	4

The EXCEL Spreadsheets for RAP

Before you start!!! – Make a copy (renamed) of the file "**Rapid Appraisal and Benchmarking BLANK.xls**" (or a file with a similar name having the word "BLANK" in it) and store the original file in a safe location. Every time you begin a new project, make a new copy of the original and use the new copy for that new project.

The worksheets for RAP are described in the Table below

Worksheets Within the EXCEL File	Worksheet Description
1. Input – Year1	For an average water year, requires input (mostly monthly) of: - Crop names - Irrigation Water Salinity - Crop threshold ECe values - Field crop coefficients, by month - Areas of crops - Water supply - Precipitation - Recirculation and groundwater pumping - Special agronomic requirements
4. External Indicators *(ignore these, except to input needed "CI" values)*	Automatic computations of monthly and annual values of various water supply indicators. These are temporary values- except the user must input "CI" values. The final, important values can be found in the worksheet '14. World Bank BMTI Indicators'
5. Project Office Questions	Most of the data for this sheet are obtained from the Project office. They include: - General project conditions - Water supply location - Ownership of land and water - Currency - Budgets - Project operation, as described by office staff - Stated water delivery service at various levels in the system.
6. Project Employees	Requests information regarding employee training, motivation, dismissal, and work descriptions.
7. WUA	Data for Water User Associations (WUA) that were not obtained in the "Project Office Questions" are obtained here. This requires asking questions in the Project Office as well as having interviews with Water User Associations. Questions are related to: - Size of WUAs - Strength of organization - Functions - Budgets - Water charges
8. Main Canal	Data for the Main Canal, including - Control of flows - General canal characteristics - Cross regulators - General conditions - Operation rules - Turnouts - Communications - Regulating reservoirs - The level of service provided to the next lower level
9. Second Level Canals	Same as Main Canal
10. Third Level Canals	Same as Second Level Canals
11. Final Deliveries	Information regarding the level of water delivery service to individual ownership units, and at the last point of operation by paid employees.
12. Internal Indicators	This worksheet summarized the internal indicators that were calculated in the previous worksheets, plus asks for input regarding a few extra indicators. Weighted category indicators are computed for groups of sub-indicators.
13. Benchmark Indicators *(ignore these)*	This worksheet holds intermediate calculated values. Ignore this page.
14. World Bank BMIT Indicators	This, plus worksheet 12, provide the final summary for the exercise.

General Guidelines for EXCEL Worksheet Usage

Names and Types

1. The **worksheet** names within any EXCEL file are identified at the bottom of the screen. These must not be changed.
2. The EXCEL file has two general types of worksheets:
   a. **Input** worksheets. These worksheets request data.
      i. In the first worksheet, the data is manipulated and/or used in computations on the far right hand side of the data sheets, out of view of the input pages. If one is interested, some computations can be seen by scrolling the pages to the right.
      ii. In the worksheets numbered 5 - 11, a few internal computations appear vertically in line with input data.
   b. **SUMMARY** worksheets. These are worksheets 4, 12, 13, and 14. The two important ones are 12 and 14. Worksheets 4 and 12 require a limited number of input values, but their primary function is to summarize various data, computed values, and indicators.

Cell Coloring and Input Conventions

1. The color convention for the first Input – Year"x" worksheet is as follows:
   a. Blank cell – indicates a place for data input
   b. Shaded cell – contains a default or calculated value or an explanation, or indicates that no data entry is required. In general, any values within the shaded cells should not be changed unless one understands all of the programming.
   c. Red letters – indicate computed values
   d. Blue values – indicate values that were transferred from elsewhere in the file. They may be computed or input elsewhere.
2. The color convention for the worksheet 4. – External Indicators is as follows:
   a. Blank cell – in the "Est. CI" column only – requires the manual input of a value.
   b. Shaded cell – indicates values that are linked to previous worksheets or are calculated within this worksheet.
   c. Red letters – indicate values computed within this worksheet.
   d. Blue values – indicate values that were transferred from elsewhere in the file.
3. Conventions for all worksheets 5-13 are:
   a. Blank cells with a light lined border require input.
   b. Blank cells with a dark lined border indicate that the value is needed, but that it requires information that may only be available at a later time.
   c. Any cell that is filled with a pattern or which is shaded should not receive input.
   d. Shaded cells contain formulas and will show the results of automatic computations.
   e. Cells with patterns are merely dividers between sections, or indicate that no data is needed.

The first INPUT worksheet requires data for a single year, but it is important to provide data for multiple years (i.e, run the program several times with new data), because an examination of only a single year can be misleading for many projects that have wide fluctuations in climate and water supply.

Worksheet Descriptions

Worksheet 1. Input – Year 1

The worksheet contains 10 tables that require data, as well as various individual cells for specific information. Information requests are described below.

Prior to Table 1

1. Total project area: This is the gross project area (ha), including fields that are supported by a project water delivery infrastructure ("command") and fields that are not supported by the infrastructure.

2. Total field area in the command area: This is the number of hectares that are supported by a project water delivery infrastructure. There may be some zones of this command area that never receive water because of infrastructure damage, due to shortage of water, etc.

3. Estimated conveyance efficiency for external water:

$$\text{Conveyance Efficiency} = \frac{\text{Volume of external irrigation water delivered}}{\text{Volume of external irrigation water at the source(s)}} \times 100$$

   Where, in this case, the "point of delivery" is where farmers take control of the water – that is, where the Water User Association and Project Authorities hand the water over. Sometimes a turnout (offtake) represents the final point of delivery by an irrigation authority, yet that turnout supplies 100 fields.

   Conveyance losses include seepage, spillage, water lost in filling and emptying canals, evaporation from canals, evapotranspiration from weeds along the canals, etc.

   The conveyance efficiency includes losses that occur between the point of original diversion and the entrance to the command area, which in some cases may be many kilometers apart.

4. Estimated conveyance efficiency for internal project recirculation.
   This is the conveyance efficiency for water that originates within the project, by project authorities. That is, it includes water that the agency pumps from wells or drain ditches or other internal sources. It does not include any water that is imported into the project boundaries.

5. Estimated seepage rate for paddy rice.

   There will only be an answer here if paddy rice is grown in a project. This is the percent of water applied to fields that goes below the root zone of the rice. Seepage rates are often expressed in mm/day, in which case they must be converted to a percentage of the field-applied irrigation water.

   Many studies combine "seepage" together with "evapotranspiration" for rice, to come up with a combined "consumptive use". That convention is not used in RAP, because such a combination makes it very difficult to separate ET (which cannot be recirculated or reduced) from seepage water (which can be recirculated via wells or drains). Furthermore, such a convention ignores the fact that deep percolation is unavoidable on all crops, not just on paddy rice. Therefore, the convention would apply to all crops, not just paddy rice.

6. Estimated surface losses from paddy rice to drains.
   There will only be an answer here if paddy rice is grown in a project. This is the percentage of irrigation water applied to fields, or groups of fields that leaves the fields and enters surface drains. This does not include water that flows from one paddy into another paddy…unless it ultimately flows into a surface drain.

7. Estimated field irrigation efficiency for other crops.
   This is an estimate for non-rice crops. The elements of inefficiency for paddy rice (deep percolation and surface runoff losses) have already been dealt with.
   The term "irrigation efficiency" has a rigorous definition (Burt et al., 1997). But the nature of a RAP is such that the values required for the rigorous application of the definition will not be available. Therefore, for the purposes of this RAP,

$$\text{Field Irrigation Efficiency} \approx \frac{\text{Irrigation Water Used for ET and Special Practices}}{\text{Irrigation Water Applied to the Field}} \times 100$$

where

- the only water considered in the numerator and denominator is "irrigation" water. Water from precipitation is not included, since this indicator is a measure of how efficiently irrigation water is used.
- "Special practices" include water for leaching of salts, land preparation, and climate control. However, for each of these categories, there is an upper limit on the amount that is accepted as beneficial use (and that can be included in the numerator). The RAP computations include an estimate of actual leaching requirement needs. The water assigned for land preparation for rice should not include excess deep percolation (caused by holding water too long on a field) or water that flows off the surface of a field.
- For crops such as rice, which are often farmed as a unit that includes several fields that pass water from one field to another, "field" efficiency can be based on the larger management unit of several smaller field parcels.

In general, this value is a rough estimate. The spreadsheet computes a correct value of "field irrigation efficiency" in the worksheet "4. External Indicators" (Indicator No. 31), which should be compared against this assumed value.

This value is only used for one purpose in the spreadsheet: To estimate the recharge to the groundwater from field deep percolation. If, upon completion of the RAP, this estimate is different from the computed estimate, the RAP user should adjust this assumed value (and/or the rice deep percolation and surface runoff values) until Indicator 2 approximately equals Indicator 31.

8. Flow rate capacity of the main canal(s) at diversion point(s).
   This value should reflect the sum of the actual (as opposed to "design") maximum flow rate capacities from each diversion point. Sometimes the actual capacities are higher than the original design capacities, and in other cases they have been reduced due to siltation or other factors.

9. Actual peak flow rate into the main canal(s) at the diversion point(s).
   The purpose of this question is to define the maximum flow rate of irrigation water that enters the project boundaries. It should not include any internal pumping or recirculation of water.

10. Average ECe of the Irrigation Water.
    If possible, this "average" should be the annual weighted average, based on the salt load (ppm × flow rate × time). It should be computed as a combination of the well water and surface water.

Table 1 – Field Coefficients and Crop Threshold ECe.

1. Water Year Month. The table provides 12 cells at the top of the Field Coefficient section into which the names of all 12 months are to be placed. Although the table could have had a default month of "January" in the first cell, many projects have "water years" that begin at other months – such as April in Southeast Asia or October or November in Mexico. Place the appropriate month in the highlighted empty cell to begin the water year accounting.

2. Irrigated Crop Name
   This column allows the user to input the names of the irrigated crops in the command area. A total of 17 crops are allowed, although the first 3 are already assigned to "Paddy Rice", leaving 14 other names blank for the user. Although a command area may have more than 17 crops, in general many of these crops have small areas of cultivation and for practical purposes can be lumped together as a single crop category.

   If a crop is double cropped, then that crop name should be entered twice. The table already has default names for 3 paddy rice crops, because so many projects have 3 or more rice crops per year. **You cannot over-ride the paddy rice crops; you cannot substitute other names for these 3 entries because certain computations assume rice in these cells.**

   Crop names only need to be entered once – into Table 1. They are automatically carried into all other tables that require crop names. This ensures consistency between tables.

3. Salinity.
   a. Average Irrigation Water Salinity (ECw), dS/m. The average salinity of the irrigation water that comes into the project. The units of dS/m are equivalent to mmho/cm.
   b. Threshold ECe, dS/m. This is the salinity of a saturated soil paste extract at which a crop yield will begin to decline. Example values are found in Table A.

Table A. Salt tolerance of various crops to soil salinity, after germination. (After Maas and Hoffman, 1977).

Crop	Threshold ECe (ECe at initial yield decline) dS/m	Crop	Threshold ECe (ECe at initial yield decline) dS/m
Alfalfa	2.0	Onion	1.2
Almond	1.5	Orange	1.7
Apricot	1.6	Orchard grass	1.5
Avocado	1.3	Peach	1.7
Barley (grain)	8.0	Peanut	3.2
Bean	1.0	Pepper	1.5
Beet, garden	4.0	Plum	1.5
Bermuda grass	6.9	Potato	1.7
Broad bean	1.6	Rice, paddy	3.0
Broccoli	2.8	Ryegrass, perennial	5.6
Cabbage	1.8	Sesbania	2.3
Carrot	1.0	Soybean	5.0
Clover	1.5	Spinach	2.0
Corn (forage and grain)	1.8	Strawberry	1.0
Corn, sweet	1.7	Sudan grass	2.8
Cowpea	1.3	Sugar beet	7.0
Cucumber	2.5	Sugarcane	1.7
Date	4.0	Sweet potato	1.5
Fescue, tall	3.9	Tomato	2.5
Flax	1.7	Wheat	6.0
Grape	1.5	Wheat grass, crested	3.5
Grapefruit	1.8	Wheat grass, tall	7.5
Lettuce	1.3		

The leaching requirement (LR) for each crop is computed within the spreadsheet as:

$$LR = \frac{ECiw}{(5 \times ECe) - ECiw}$$

where
ECiw = EC of the irrigation water, dS/m
ECe = Threshold saturated paste extract of the crop, dS/m

For example, if
ECiw = 1.0 dS/m
Crop = grain corn
From Table A, ECe = 1.8 dS/m

$$LR = \frac{1}{(5 \times 1.8) - 1} = .125$$

The extra water required for each crop, to remove salinity that arrives with the irrigation water, is then computed as:

$$\text{Extra water for salinity control} = (\text{ET of irrigation water}) \times \frac{LR}{1 - LR}$$

For example, if for a specific crop,
ET of irrigation water = 100,000 MCM
LR = .125

The volume of water needed for salinity control = 14,286 MCM

However, deep percolation of rainwater will accomplish the same task (it washes accumulated salts out of the root zone). Therefore, this RAP approximates the irrigation water requirement as:

Volume of irrigation water needed for salinity control=
Volume of water needed for salinity control
\- Rainfall deep percolation

4. Field coefficients.
Most irrigation specialists are familiar with the term "crop coefficient". Crop coefficients have been widely used in estimates of crop evapotranspiration (ET) since the mid-1970's. The general formula used is:

$$ETcrop = Kc \times ETo$$

where

Kc = the crop coefficient
ETo = grass reference ET

Guidelines for estimating ET and ETo are found in FAO Irrigation and Drainage Paper 56 – "Crop Evapotranspiration – Guidelines for computing crop water requirements" (Allen et al, 1998).

"Reference" values other than ETo are sometimes used, but they are quickly being replaced with weather stations that provide the hourly data needed to compute ETo. This spreadsheet uses ETo as defined in FAO 56 because

a. ETo is today's standard "reference".
b. The majority of excellent ET research on a variety of crops uses ETo as the reference crop.
c. ETo estimates tend to be more accurate than other reference methods such as evaporation pans.

If the only local data is from evaporation pans, it is recommended that users consult with FAO 56 to determine the proper conversion from monthly Epan to monthly ETo values. The table below comes from page 81 of FAO 56, where

$$ETo = Kp \times Epan$$

Table B. Pan coefficients (Kp) for Class A pan for different pan siting and environment and different levels of mean relative humidity (RH) and wind speed (FAO 56)

Class A Pan Description→	Case A: Pan placed in short green cropped area				Case B: Pan placed in dry fallow area			
RH mean (%) →		low (<40)	medium (40 – 70)	high (>70)		low (<40)	medium (40 – 70)	high (>70)
Wind speed (m s^{-1})	Windward side distance of green crop (m)				Windward side distance of dry fallow (m)			
Light (<2)	1	.55	.65	.75	1	.7	.8	.85
	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1000	.75	.85	.85	1000	.5	.6	.7
Moderate (2-5)	1	.5	.6	.65	1	.65	.75	.8
	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75	.8	100	.5	.6	.65
	1000	.7	.8	.8	1000	.45	.55	.6
Strong (5-8)	1	.45	.5	.6	1	.6	.65	.7
	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1000	.65	.7	.75	1000	.4	.45	.55
V. Strong (>8)	1	.4	.45	.5	1	.5	.6	.65
	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1000	.55	.6	.65	1000	.34	.4	.45

This spreadsheet uses the term "field coefficient" because quite often a "crop coefficient" is only used during the crop-growing season, and quite often the common usage of "crop coefficients" ignores the impacts of soil moisture contents.

In reality, the "field coefficient, Kc" is the same as the "crop coefficient, Kc" if the crop coefficient is properly adjusted (using FAO 56 guidelines) to include factors such as

* stress (reduced transpiration) due to a dry root zone
* soil surface evaporation due to rainfall or irrigation.

The proper selection of Field Coefficients depends upon a good understanding of Table 8 in the INPUT spreadsheets (Precipitation, effective precipitation, and deep percolation of precipitation). The computation procedure that the spreadsheet uses includes the following:

a. <u>Effective</u> precipitation and irrigation water are assumed to be the only external sources of water for field ET.

b. The field ET is computed on a monthly basis as:

$$ET = Kc \times ETo$$

Effective precipitation includes all precipitation that is lost through either evaporation (from the soil or plant) or transpiration, as computed by the formula above. Therefore, if one wants to account for soil evaporation for those months when the crop is not in the ground, one must do 2 things simultaneously:

a. The effective precipitation must be computed to account for that evaporation, and
b. A field coefficient (Kc) of greater than 0.0 must be applied to those months.

The following procedure is recommended for RAP:

a. For crops with no irrigation water used for pre-plant irrigation. If for a month the crop has not yet been planted, or a crop is not in the field, assume that for that month,
   - crop coefficient = 0.0
   - effective rainfall that is reported for that month will only include water that is stored in the root zone for ET after the seeds are planted.
b. For crops that use irrigation water for pre-plant irrigation (e.g., rice field preparation, cotton pre-irrigation). Follow the procedure of (a) above until the irrigation water is first applied. Then do the following for each month until the crop is planted or transplanted:
   - crop coefficient > 0 to account for soil evaporation of both irrigation water and effective rainfall.
   - effective rainfall that is reported for that month will include water that is stored for ET after planting, plus the rainfall contribution to the soil evaporation prior to planting.

As an example, assume a case in which

- A pre-plant irrigation is applied to a field on the first day of the month.
- The crop will not be planted for another month.
- The soil remains bare and free from weeds for this month.
- The soil remains "dark" for 3 days after standing water disappears from the soil surface.

Table C indicates how to compute an average monthly Kc that properly takes into account the soil evaporation. Rules to follow include:

- The minimum value of Kc is typically 0.15
- If a soil surface is dark in appearance from moisture, even if there is no standing crop, a crop coefficient of 1.05 is appropriate.
- Most unstressed field crops (cotton, rice, corn) have a crop coefficient of approximately 1.1 once they have achieved 100% canopy cover.

Table C. Example computation of an average monthly Kc value for a month following a pre-plant irrigation, but prior to planting.

Day	Kc	Explanation
1	1.05	Irrigation - wet soil surface
2	1.05	2nd day of irrigation - wet soil surface
3	1.05	1st day after irrigation. No standing water. Soil surface still dark
4	1.05	2nd day after irrigation. Soil surface still dark
5	1.05	3rd day after irrigation. Soil surface still dark
6	0.7	4th day after irrigation.
7	0.5	5th day after irrigation.
8	0.3	6th day after irrigation.
9	0.15	7th day after irrigation
10	0.15	8th day after irrigation
11	1.05	Rain - wet soil surface
12	1.05	2nd day of rain - wet soil surface
13	1.05	1st day after rain. Soil surface still dark
14	1.05	2nd day after rain. Soil surface still dark
15	1.05	3rd day after rain. Soil surface still dark
16	0.7	4th day after rain.
17	0.5	5th day after rain.
18	0.3	6th day after rain.
19	0.15	7th day after rain
20	0.15	8th day after rain
21	1.05	Rain - wet soil surface
22	1.05	2nd day of rain - wet soil surface
23	1.05	1st day after rain. Soil surface still dark
24	1.05	2nd day after rain. Soil surface still dark
25	1.05	3rd day after rain. Soil surface still dark
26	0.7	4th day after rain.
27	0.5	5th day after rain.
28	0.3	6th day after rain.
29	0.15	7th day after rain
30	0.15	8th day after rain
Avg. Kc =	**0.71**	for this month of 30 days

Table 2 – Monthly ETo values

ETo (mm) values by month should be entered. See the earlier discussion regarding crop coefficients. Ideally, ETo should be computed on an hourly basis using the Penman-Monteith method, following the procedure by Allen, et al (1998).

Table 3 – Surface Water Entering the Command Area Boundaries (MCM).

All values for this table should be in units of million cubic meters (MCM), and should only include water that can be used for irrigation. In other words, flows from a river flowing through a command area that has no diversion structures or pumps would not be included. The table allows for 3 general categories of surface inflows:

1. Irrigation Water Entering from outside the command area. The MCM should be the total MCM at the original diversion point(s). Therefore, technically speaking it is not the

MCM entering the command area. This category of "irrigation water" is the "officially diverted" irrigation water supply.

2. Other inflows from external source #2. This source can be defined by the RAP user, and can be a consolidation of several physical sources – but all placed in one category. However, these inflows must be accessed by users within the command area as an irrigation supply – either through diversion or through pumping from rivers.
3. Other inflows from external source #3. This has the same qualification as #2.

The key concepts for Table 3 are these:

1. Table 3 only includes surface volumes that enter from outside the command area boundaries.
2. The surface volumes are only included if they are volumes of water used for irrigation. For purposes of the RAP, External Sources #2 and #3 are considered irrigation water if they consist of water that individual farmers or groups of farmers divert or pump. Many projects have such supplemental supplies that do not enter the command area through designed and maintained canals, yet these supplies are important parts of the overall irrigation supply in the command area.

   The important value here is the volume of water that enters the command area, NOT the volume of water that is pumped from drains….since that may also include recirculation of spills and field runoff.

Table 4 – Internal Surface Water Sources (MCM)

Table 4 values do not represent original supplies of water, since the surface sources were already accounted for in Table 3. Rather, this is the volume of water that is recirculated or pumped from surface sources within the project. This may be water that originated from the irrigation canal and was spilled, deep percolated, or ran off from fields. The origin of the water is not the important thing in Table 4. Rather, the important feature for Table 4 is which entity diverts or pumps this non-canal water.

Table 5 – Hectares of Each Crop in the Command Area, by Month

Table 5 provides information on how much area is used for each crop during each month.

The Kc values for each crop are found in the row immediately above the row into which you must input the hectares of that crop. ***If a Kc value greater than 0.0 exists for a month for that crop, you must input the number of hectares associated with that crop, for that month***.

Table 6 – Groundwater Data

These questions only need to be answered if groundwater is used by farmers or by the project authorities.

Groundwater accounting in irrigation projects frequently ignores external sources of groundwater, and the fact that much of the groundwater may simply be recirculated surface water. This RAP eliminates the double counting of recirculated water, which is what happens if groundwater is treated as an independent supply.

Table 6 recognizes that an aquifer may extend well beyond the confines of the command area.

The questions are divided into 2 categories – pumping from the aquifer within the command area, and pumping from the aquifer but outside the command area. Both areas must be considered if the aquifer is to be examined properly. The External Indicators and Benchmarking indicators do not utilize the external pumping information. However, frequently the pumping from outside the command area is completely dependent upon seepage and deep percolation from within the command area. In such a case, a "water conservation" program within the command area to minimize seepage may actually eliminate the water source for groundwater pumpers outside the command area. Of course, there may be considerations such as contamination of the groundwater as it passes through old marine sediments – increasing the salinity of groundwater as compared to surface water.

The "net" groundwater pumping within the command area can only be greater than or equal to zero, the way the spreadsheet is designed. The computations is this:

- Estimates of deep percolation from fields are made.
- Estimates of seepage from canals is made

These two, when combined, represent the recharge of the aquifer from external irrigation water.

Estimates are then made of the groundwater pumping that occurs within the command area – either by project authorities or by individual farmers. This groundwater pumping volume is then discounted for estimated losses. The result is an estimate of the groundwater that actually contributes to evapotranspiration.

The volume of groundwater that is used for ET is compared against the recharge from surface water supplies. If the recharge is greater than the ET of groundwater, then the "net" groundwater pumping = 0.0. If the ET of groundwater is greater than the recharge, the difference is the "net" groundwater pumping. In most projects, the "net" groundwater pumping will equal zero because typically the aquifer is recharged with the imported surface irrigation water.

Although groundwater pumping is an important aspect of recirculation of irrigation water, it is not a "new" supply of water any more than recirculation of surface water would be. However, recirculation of any type will increase the irrigation efficiency of the project – but it will not have any impact on the irrigation efficiency of the field units, unless the recirculation occurs on the fields themselves.

Table 7 – Precipitation, Effective Precipitation, and Deep Percolation of Precipitation.

The monthly gross precipitation (mm) is required at the top of the table. These values are generally easily obtained.

The other values are probably somewhat of a mystery to most users, although the concepts of effective precipitation and deep percolation are common concepts. The problem the user will have is in identifying proper values. Unfortunately, simple assumptions about deep percolation and the percentage of rainfall that is effective do not work for spreadsheets such as this, that are designed to be applied over a wide range of geography, each having vast differences in climates and crops.

Effective precipitation is defined as precipitation that is destined for ET (evaporation or transpiration) either this month or in the future.

Effective precipitation and deep percolation can be input in this table for any or all months, regardless of whether a crop is in the field that month. The deep percolation of rainfall is used for only one computation purpose: as a computed reduction of the amount of irrigation leaching water that is necessary to wash salts from the root zone.

In general, values for “effective precipitation” and “deep percolation” are not available as monthly values, and they are almost never available for individual crops. Nevertheless, it is important to make an estimate of these values.

As an aid to the spreadsheet user, the calculated ETfield (mm) values are carried forward from previous tables (these tables are found on the far right hand side of the pages of this Worksheet, and include computations using ETo and Kc values). Once the spreadsheet user inputs an estimate of the percentage of effective precipitation, a corresponding depth of effective precipitation appears in the next row.

In general, if there is a light rainfall during a month yet the ETfield is high, there will be very little deep percolation of rainfall. Conversely, if there is a large amount of rainfall and very little ETfield, then one can expect more deep percolation. Deep percolation will depend upon the soil type, also – sandy soils have more deep percolation than do clay soils. The deep percolation cannot exceed the quantity: (Precipitation – Effective Precipitation)

Table 8 – Special Agronomic Requirements (mm)

Only a few crops will have values in this table. The most notable crop is paddy rice.

As an example for a rice crop, assume the following:

EXAMPLE
A rice field needs to be flooded prior to planting.
Flooding - March 1
Planting - March 15

The field stays covered with a small depth of water the complete time, or at least the soil is very wet the complete time. Therefore, the “field coefficient, Kc” equals 1.05

Assume a monthly ETo of 120 mm during March

Furthermore, assume that the field coefficient, Kc was computed following the example at the beginning of this document. The difference between this example and the earlier example is that this example is very simple – the soil is always wet, so the Kc always equals 1.05

If the crop coefficient for March was entered as 1.05, then ET for the whole month of March will be computed separately. Therefore, Table 9 would not include any ET amount that occurs between March 1 and March 15.

If, however, the crop coefficient for March was entered as 1.05/2 = 0.53, this would indicate that the spreadsheet user only wants to count the ET starting March 15 as "crop ET", and the ET between March 1 and March 15 would be included in Table 8. It is recommended that the first approach be used (use a Kc of 1.05 for the month).

Assuming that the first approach is used (Kc = 1.05 for March), then the value in Table 8 must only include 2 things:

- The deep percolation amount of irrigation water
- The amount of irrigation water that runs off the field, or group of fields, into surface drains.

If there was rainfall during March, some of the runoff and deep percolation would have been rainwater. Table 8 only includes irrigation water amounts, so any rainfall amounts must be subtracted from total seepage and runoff.

Table 9 – Crop Yields and Values

Three types of input are needed:
1. The local exchange rate ($US/local currency)
2. Typical average yields of each crop, in metric tons per hectare.
3. The farm gate selling price of each crop, in (Local currency/metric ton).

Worksheet 4. External Indicators

This worksheet is a temporary holding place for some values and computations.

For the user, the primary usage of this worksheet is to enter confidence interval values.

Internal Indicator Section

Worksheets 5 – 12 require a good field visit to the project by qualified evaluators. They focus on how the project actually works – what the instructions are, how water is physically moved throughout the canal/pipeline system, what perceptions and reality are, and other items such as staffing, budgets, and communication. A quick look (Rapid Appraisal) of these items will immediately identify weaknesses and strengths in the project. Action items are virtually always readily apparent after the systematic RAP has been conducted.

At first glance, the large number of pages in worksheets 5-12 appears daunting. However, a close examination of the pages will show that only about 25% of the lines require an answer (the other lines are explanations or blanks), and computations are only necessary for a few items such as budget questions. Furthermore, the questions for the Main Canal are identical to those of the Second Level Canals and the Third Level Canals. Once an evaluator understands the Main Canal questions, the remainder of the pages are easily answered after a field visit.

Worksheet 5. Project Office Questions

Most of the questions in this worksheet should be filled out by the Irrigation Project employees prior to the visit, as this includes many simple data values such as salaries, number of employees, and stated project policies.

However, the evaluator must answer some of the questions during the visit.

This worksheet includes questions that address the possibility of chaos existing in a project. “Chaos” exists when the reality in a project does not match what project authorities believe occurs. Therefore, the evaluator must ask the project authorities what levels of water delivery service the main canal delivers, what various operators do, and how water arrives to individual farmers. These “stated” conditions are later compared against what the evaluator actually observes in the field.

In general, it is easiest to modernize irrigation projects that have a minimum of chaos. If the project authorities are either not aware of actual field conditions, or if they refuse to recognize certain problems, it is then very difficult to make changes.

This worksheet also introduces the concept of assigning a rating of 0-4 to project characteristics, with 0 being the worst rating and 4 being the best. In the majority of cases, the evaluator reads a series of descriptions, and assigns a rating to each of “internal indicators” that are later summarized in worksheet “12. Internal Indicators”.

Some indicator values (such as “O&M adequacy”) are automatically calculated based on previous answers. The rating scale for those values can be found if one highlights the calculated value and reads the formula in the cell.

This worksheet has some Drainage and Salinity Information questions at the very end. Those are used in various benchmarking indicators.

If there is an "umbrella" Water User Association (WUA), elected by smaller Water User Associations, that manages the project, then that "umbrella" WUA is considered part of the "project office".

Worksheet 6. Project Employees

Most of these questions require a qualitative assessment of conditions in the project, with the evaluator giving a rating of 0-4 for each question. Topics include:

- Adequacy of employee training
- Availability of written performance rules
- Power of employees to make independent decisions
- The ability of the project to fire employees with cause
- Rewards to employees for good work

Worksheet 7. WUA

In the worksheets, the abbreviation WUA stands for "Water User Association". Some irrigation projects have a large WUA that operates the whole project canal system, but the final water distribution is done by many smaller WUA. In such a situation, the WUA questions pertain only to the smaller WUA.

Many of the questions are identical to those used in worksheet 5. Project Office Questions.

The answers must reflect average conditions throughout the whole irrigation project, rather than any single WUA. Therefore, several WUAs must be visited to properly answer the questions.

Worksheet 8. Main Canal

This worksheet begins with 6 questions about general conditions throughout the project. The answers will have a large confidence interval (defined earlier, in the section covering external indicators), but because there are large differences between various projects, the answers are meaningful.

The remainder of the questions are identical to those for the Second Level and Third Level Canals. Most of the questions are self-explanatory, but a few points deserve special explanations

1. Wave travel time. This is the lag time between making a change in flow rate at one point in a canal, and having the change stabilize at another point downstream.
2. Functionality of various structures and instructions. An evaluator must always consider the operations from the point of view of the operator, and ask himself/herself "If I was to

walk up to this structure, how would I know what to do and would it be easy to do?". For example, if the objective is to maintain a constant water level with a structure, what does "constant" mean – within 1 centimeter, or within 5 centimeters? And how many times/day would the structure need to be moved, and even with that movement would it be possible to achieve the desired result? And is the structure dangerous or difficult to operate?

If an operator is told to deliver a flow rate into a canal, yet there is no flow rate measurement device (or the device is inaccurate, improperly maintained, improperly located, or requires significant time to stabilize), then it will be almost impossible to accurately achieve the desired result.

Therefore, the evaluator must not just listen to explanations. The evaluator must put him/herself into the operator's shoes. It isn't sufficient to know that the operator moves something and then looks at something; the evaluator must understand if those "somethings" do indeed give the proper answer, etc.

The format of the worksheet 8. Main Canal is this:
1. General observations are recorded.
2. Ratings are given to various aspects of operation, maintenance, and process. Some of these ratings depend upon the general observations that are recorded in the same worksheet. Other ratings stand on their own.

It may appear that some of the general observations are not necessary because they are addressed later in the form of ratings. However, they have been included to force the evaluator to make a more systematic examination of various features – which are summarized in later ratings.

The questions about actual SERVICE are key. RAP evaluators must recognize that the **RAP has been designed under the assumption that all employees of an irrigation project only have their jobs for one reason – to provide service to customers**.

When one analyzes a project by "levels" (office, main canal, second level canal, third level canal, distributaries, field), a huge project can be understood in simple terms. The operators of the main canal only have one objective – everything they do should be done to provide good water delivery service to their customers, the second level canals (and perhaps a few direct turnouts from the main canal). This "service concept" must be understood and accepted by everyone, from the chief engineer to the lowest operator. Once it is accepted, then the system management becomes very simple. Personnel on each level are only responsible for that level's performance.

Main canal operators do not need to understand the details of that day's flow rate requirements on all the individual fields. Of course, in order to subscribe to the service concept, operators generally need to know that their ultimate customer is the farmer. But the details of day-to-day flow rates do not need to be known at all levels.

Rather, the main canal operators have one task to accomplish – to deliver flow rates at specific turnouts (off takes) with a high degree of service. Service is described in RAP with 3 indices:

a. Flexibility, composed of
   - Frequency
   - Flow rate
   - Duration
b. Reliability
c. Equity

For very simple field irrigation techniques, reliability and equity are crucial. Without good reliability and equity, there are generally social problems such as vandalism and non-payment of water fees. Reliability and equity, then, are cornerstones of projects that have good social order.

In order to have efficient field irrigation practices, some minimum level of flexibility is required. Even with the most simple irrigation methods such as paddy rice, the flow rates are completely different at the beginning of the season (for land preparation), compared to when the rice crop is established. And not everyone plants at the same time, meaning that the irrigation project must have some flexibility built into it.

To obtain a high project efficiency, the canal system must have sufficient flexibility built into it to be able to change flows frequently in response to continually changing demands and weather. There is no doubt that most irrigation projects are not very flexible. There is also no doubt that most irrigation projects have low project efficiencies.

Finally, the evaluator must consider that **a major purpose of the RAP is to identify what can be done to improve project performance**. Modern field irrigation methods, such as sprinkler and drip, require a much higher degree of flexibility and reliability than do traditional surface irrigation methods. The evaluator must always be asking him/herself during the RAP:

> "I don't only want to recommend how to rehabilitate the project – I want to recommend steps that will move the project closer to a higher efficiency and better water management as the future will certainly demand. Will these structures and operating instructions and personnel be capable meeting the new requirements, and if not, what adjustments must be made?"

Therefore, the examination of the main canal must be thorough. The evaluator must start at the source, and go all the way to the downstream end of the canal. This is not to say that every single structure must be analyzed. But an evaluator must examine key structures along the complete length of the canal.

Common challenges that must be overcome by the evaluators include:

1. The project authorities want to spend a disproportionate amount of time at the dam, discussing dam maintenance, the watershed, and politics. Actually, the only items of

interest at the dam are (a) the storage, and (b) how discharges are computed and actually made and measured.

2. Evaluators will be told, "the canal is all the same". The explicit or implied conclusion is that the evaluator only needs to examine portions of the canals near the headworks. While it may be true that the canal is indeed identical along its complete length, in general there are significant differences in maintenance, slope, structures, etc. along its length. Only by physically traveling along the canal will the evaluator learn about those differences.
3. The operation will be explained by project authorities that are driving with the evaluators. This is definitely a difficult challenge. The office visit (worksheet 5) is designed to obtain the perspective of the office staff and bosses. A purpose of the field visit is to talk to the actual structure operators and review their notes – without having their bosses interrupt and give the "official" answer. In many cases, it is necessary to separate the bosses from the operators, so that the operators are not cautious with the answers they give. Therefore, the "rules of the game" must be understood before the field visit is made.

Another challenge arises in the selection of which canals to visit. Sometimes a project will have 2 or more main canals, and dozens of "second level" canals. The good news is that in general, operator instructions, hardware, and maintenance levels will be similar on all of the canals at a specific level. Visiting more canals is helpful, but it is not necessary to visit all of the canals in a project.

There is no doubt that different main canals each have a few specific engineering/hydraulic challenges. One canal may have a bottleneck (restriction) at a river crossing, and another canal may have a peculiar control problem – even though everything else seems the same. If the RAP evaluator can provide good recommendations for those specific hydraulic problems (that are not covered specifically in the RAP forms), the credibility of the evaluator will be enhanced, and RAP recommendations will have a better chance of being accepted. Therefore, the evaluator should take ample pictures and notes during the visit.

Basic advice for evaluators as they tour the main, second, third, etc. levels of canals is this:

> Understand everything. Understand how the operators THINK things should work. Question everything. If you do not understand explanations, continue to question the explanations until you understand the perspective of the operators. But go beyond that. Every structure has a function. Do not be satisfied with attempting to visualize how that function can be accomplished easier or better; question the very reason that the structure has been assigned that function. Perhaps in a modernization plan, a structure that is presently operated under flow rate control should be operated instead under upstream water level control. In other words, question the very nature of the strategies of operation – not just individual structures. <u>The RAP is not an examination of individual structures – it is a comprehensive examination of a whole process</u>…in which structures have functions. One must understand the pieces (operators, rules, structures) to understand the process, but RAP also

questions the assumptions behind the specific processes, themselves. **RAP requires evaluators who can look beyond the individual pieces; it requires evaluators who can visualize how the pieces can be manipulated and re-arranged as parts of a complete process that provides good service and high efficiency**.

Worksheet 9. Second Level Canals

See the discussion for Worksheet 8. Second Level Canals are those that receive water from the Main Canals. In general, the Second Level Canals are operated differently than the Main Canals.

Worksheet 10. Third Level Canals

See the discussion for Worksheet 8. In many medium sized projects, the "Third Level" does not exist, so this worksheet would not be filled out in those cases.

Worksheet 11. Final Deliveries

There are two possible points that are considered in this workshop. One is the Individual Ownership Units – the smallest unit that is owned by a single individual (if private ownership is allowed) or that is managed by a farmer. The Individual Ownership Unit may be larger than a single field if one farmer receives water and then distributes the water over several fields from a single turnout (very common in the USA). The key feature of the Individual Ownership Unit is that at this point, there is no cooperation needed between individual farmers.

The second point is the Point of Management Change. In projects with a high density of turnouts, the Point of Management Change may be the same as the point of Individual Ownership Units. In other words, the irrigation project authority (or the water user association) employee delivers water all the way to the field level. The Point of Management Change is the "hand-off" point between paid employees and volunteers or farmers.

In some projects, the irrigation authorities place great emphasis on the number of farmers within a project. One must go beyond that statistic when examining the present operation, because the project authorities may relinquish control of the water to groups of 200 farmers – who are expected to somehow provide equitable and reliable water distribution among themselves. Therefore, there are 2 important indicators for this discussion:

- The number of fields (Individual Ownership Units) downstream of the Point of Management Change. The greater the number, the poorer is the reliability, equity, and flexibility of water delivery service. Furthermore, any number greater than 1 or 2 indicates that drip and sprinkler irrigation are almost impossible to support.
- The number of turnouts that are operated per employee. This is much more meaningful than the "number of farmers per employee", because employees may never provide water directly to individual farmers.

Worksheet 12. Internal Indicators

This worksheet contains 3 types of values:

1. Summaries of the various internal Sub-Indicators that were rated in the previous workshops, and then computed weighted values for each Primary Indicator. The shaded columns on the right hand side provide information about the values, the weighting factors, and the worksheet location for detailed rating criteria of the Sub-Indicators. All of these values are given a rating of 0-4, with 4 being highest and most desirable.

2. Sub-Indicators and Primary Indicators, the values of which are input directly into this worksheet (as opposed to being transferred from previous worksheets). These are Indicators I-32, I-33, and I-34. These values all have a rating of 0-4.

3. A few Indicators (I-35+) that do not conform to the rating scale of 0-4. Rather, these are direct ratios of values or individual values that have special significance.

Worksheet 13. IPTRID Indicators

This worksheet is an intermediate worksheet that should not be used. Instead, refer to Worksheet 14, as described below.

Worksheet 14. World Bank BMTI Indicators

This worksheet contains the "Benchmarking Technical Indicators", or BMTI values as of October 2002. The definitions of the various BMTI values are given below:

Water Year described:________________________

WATER BALANCE INDICATORS

Indicator	Definition	Data specifications
Total annual volume of irrigation water available at the user level (MCM)) *(also called "irrigation water delivered")*	Total volume of irrigation water (surface plus ground) directly available to users, MCM - using stated conveyance efficiencies for surface and ground water supplies. It includes water delivered by project authorities as well as water pumped by the users themselves. Water users in this context describe the recipients of irrigation service, these may include single irrigators or groups or irrigators organized into water user groups. This value is used to estimate field irrigation efficiency; it is not used to estimate project irrigation efficiency.	Calculated from the stated value of system water delivery efficiency (from the dam or diversion point, to the final project employee delivery point). Includes farmer pumping, because this is a "delivery" in the sense that it is irrigation water that is available to the farm/field.
Total annual volume of irrigation supply into the 3-dimensional boundaries of the command area (MCM)	This is the irrigation water that is imported into the project boundaries, to include river diversions, reservoir discharges, and NET groundwater extraction from the aquifer. This value is used to estimate project irrigation efficiency; it is not used in the computation of field irrigation efficiency.	Determination of this value requires a detailed water balance if there is groundwater pumping, because the NET extraction must be estimated.
Total annual volume of irrigation water managed by authorities. (MCM)	This is the irrigation water that is imported into the project boundaries by the authority, plus any internal groundwater pumped by the authorities. The value is not used to compute any efficiencies, as some of the internal pumping may be recirculation of original source water. However, this is the volume of water that the project authorities administer, so it is used for the computations related to costs.	
Total annual volume of water supply (MCM)	Total annual volume of surface water diverted and net groundwater abstraction, plus total rainfall, excluding any re-circulating internal drainage within the scheme.	This is the irrigation water that is imported into the project boundaries, to include river diversions, reservoir discharges, and NET groundwater extraction from the aquifer. PLUS, this includes total rainfall.

Indicator	Definition	Data specifications
Total annual volume of irrigation water delivered to users by project authorities.	Total volume of water delivered to water users by the authorities over the year that was directly supplied by project authority (including WUA) diversions or pumps. Water users in this context describe the recipients of irrigation service, these may include single irrigators or groups or irrigators organized into water user groups. This does not include farmer pumps or farmer drainage diversions.	This can be directly measured, or is more commonly estimated based on an assumed conveyance efficiency.
Total annual volume of groundwater pumped within/to the command area (MCM)	Total annual volume of groundwater that is pumped by authorities or farmers that is dedicated to irrigated fields within the command area. This groundwater can originate outside of the command area.	An answer must be provided even if the user does not precisely know the volume of groundwater pumped. The uncertainty can be handled by assigning a large confidence interval, if necessary.
Total annual volume of field ET in irrigated fields (MCM)	Total annual volume of crop ET. This includes evaporation from the soil as well as transpiration from the crop. Depending upon how the user entered the data, this may include off-season soil evaporation.	This is computed based on crop coefficients and ETo values.
Total annual volume of ET – effective precipitation, (MCM)	The volume of evapotranspiration that must be supplied by irrigation water. Regardless of how one enters data for ET, above, if one follows the guidelines in this manual, one obtains the same final answer of (ET – effective ppt.) – which is the net irrigation requirement.	The user gives an estimate of the effective rainfall, by month, and by crop. Effective rain contributes to the ET.
Peak net irrigation water ET requirement (CMS)	The net peak daily irrigation requirement (ET – effective rainfall) for the command area, based on actual cropping patterns for this year. (CMS)	Calculated as the peak monthly (ET – effective rainfall) value, divided by the number of days in that month.
Total command area of the system (ha)	The physical hectares of fields in the project that that are provided with irrigation infrastructure and/or wells.	
Irrigated area, including multiple cropping (ha)	The hectares of cropped land that received irrigation. If a 1 hectare field has two irrigated crops per year, the reported irrigated area would be 2.0 hectares.	
Annual irrigation supply per unit command area (m^3/ha)	$\frac{\text{Total annual vol. of irrig. supply into the command area}}{\text{Total command area of the system}}$	*Total annual volume of irrigation supply into the command area*: See earlier definition. *Total command area of the system:* See earlier definition

Indicator	Definition	Data specifications
Annual irrigation supply per unit irrigated area (m^3/ha)	Total annual volume of irrigation supply / Total annual irrigated crop area	*Total annual volume of irrigation supply*: See earlier definition *Total annual irrigated crop area:* See earlier definition. Includes multiple cropping.
Conveyance efficiency of project-delivered water, % (Weighted value using stated values)	Volume of irrigation water delivered by authorities / (Total annual volume of project authority irrigation supply)	*Volume of external irrigation water delivere by authorities*: Total volume of irrigation water supply that is delivered to water users by the project authorities over the year. Water users in this context describe the recipients of irrigation service, these may include single irrigators or groups or irrigators organized into water user groups. *Total annual volume of project authority irrigation supply*: Defined earlier
Estimated conveyance efficiency for project groundwater (%)	Annual volume of project groundwater delivered to users x 100 / Annual volume of groundwater pumped by authorities	*Annual volume of project groundwater delivered to users* This refers to a weighted value of conveyance efficiency for groundwater that is pumped by authorities from wells both inside and outside of the command area, but which is delivered within the command area. *Annual volume of groundwater pumped by authorities* Self explanatory
Annual Relative Water Supply (RWS)	Total annual volume of water supply / Total annual volume of field ET in irrigated fields	*Total annual volume of water supply:* defined earlier *Total annual volume of field ET*: Defined earlier.
Annual Relative Irrigation Supply (RIS)	Total annual volume of irrigation supply into the 3-D boundaries / Total annual volume of ET – effective precipitation	*Total annual volume of irrigation supply into the 3-D boundaries:* Defined earlier *Total annual volume of ET – effective precipitation*: Defined earlier.

Indicator	Definition	Data specifications
Water delivery capacity	Canal capacity to deliver water at system head Peak irrigation water ET requirement	*Canal capacity to deliver water at system head:* Actual gross discharge capacity of main canal(s) at all diversion point(s). (CMS) Peak irrigation water ET requirement*:* Defined earlier (CMS)
Security of entitlement supply, %	The frequency with which the irrigation organization is capable of supplying the established system water entitlements	*System water entitlement:* The bulk volume (MCM) or bulk discharge of water (CMS) to which the scheme is entitled per annum.
Average Field Irrigation Efficiency, %	(ET - Effective precipitation + LR water) x 100 (Total Public and Private Water Delivered to Fields)	All values are expressed in 12 month volumes.
Command area Irrigation Efficiency, %	(ET + Leaching needs - Effective ppt.) x 100 (Surface irrigation imports + Net groundwater)	All values are expressed in 12 month volumes.

FINANCIAL INDICATORS

Indicator	Definition	Data specifications
Cost recovery ratio	Gross revenue collected Total MOM cost	*Gross revenue collected:* Total revenues collected from payment of services by water users. *Total MOM cost:* Total management, operation and maintenance cost of providing the irrigation and drainage service excluding capital expenditure and depreciation/renewals.
Maintenance cost to revenue ratio	Maintenance cost Gross revenue collected	*Maintenance cost:* Total expenditure on system maintenance *Gross revenue collected:* Total revenues collected from payment of services by water users.
Total MOM cost per unit area (US$/ha)	Total MOM cost Total command area serviced by the system	*Total MOM cost:* Total management, operation and maintenance cost of providing the irrigation and drainage service excluding capital expenditure and depreciation/renewals. *Total command area serviced by the system:* Defined earlier
Total cost per staff person employed (US$/person)	Total cost of personnel Total number of personnel	*Total cost of personal :* Total cost of personnel employed in the provision of the irrigation and drainage service, either in the field or office (including secretarial and administrative staff). Includes WUA employees and project employees. *Total number of personnel engaged in I&D service:* Total number of personnel employed in the provision of the irrigation and drainage service, either in the field or office (includes secretaries, administrators). This includes WUA employees and project employees.

Indicator	Definition	Data specifications
Revenue collection performance	Gross revenue collected Gross revenue invoiced	*Gross revenue collected:*. Total revenues collected from payment of services by water users. *Gross revenue invoiced:* Total revenue due for collection from water users for provision of irrigation and drainage services.
Staff persons per unit irrigated area (Persons/ha)	Total number of personnel engaged in I&D service Total irrigated area serviced by the system	*Total number of personnel engaged in I&D service:* Total number of personnel employed in the in provision of the irrigation and drainage service, including secretarial and administrative staff – in WUAs plus project employment. *Total irrigated area, ha :* (defined earlier)
Number of turnouts per field operator	Total number of turnouts (offtakes) Total number of personnel engaged in field I&D service	*Total number of personnel engaged in I&D service:* Total number of field personnel employed in the provision of the irrigation and drainage service, including supervisors. *Total number of turnouts:* The number of turnouts (offtakes) to fields, farms, or groups of farmers, plus offtakes to laterals and sublaterals, that are physically operated by the field personnel.
Average revenue per cubic meter of irrigation water delivered to water users by authorities (US$/$m^3$)	Gross revenue collected Total annual volume of project irrigation water delivered	*Gross revenue collected:* Total revenues collected from payment of services by water users. *Total annual volume of irrigation water delivered:* Defined earlier
Total MOM cost per cubic meter of irrigation water delivered to water users by the project authorities (US$/$m^3$)	Total MOM Cost Total annual volume of irrigation delivered by project authorities	*Total MOM cost:* Total management, operation and maintenance cost of providing the irrigation and drainage service excluding capital expenditure and depreciation/renewals. *Total annual volume of irrigation water delivered by project authorities: Defined earlier*

AGRICULTURAL PRODUCTIVITY AND ECONOMIC INDICATORS

Indicator	Definition	Data specifications
Total annual value of agricultural production (US$)	Total annual value of agricultural production received by producers.	
Output per unit command area (US$/ha)	Total annual value of agricultural production Total command area of the system	*Total annual value of agricultural production:* Total annual value of agricultural production received by producers. *Total command area of the system:* The command area is the nominal or design area provided with irrigation infrastructure that can be irrigated.
Output per unit irrigated area, including multiple cropping (US$/ha)	Total annual value of agricultural production Total annual irrigated crop area	*Total annual value of agricultural production:* Defined earlier *Total command area of the system:* Defined earlier
Output per unit irrigation supply (US$/$m^3$)	Total annual value of agricultural production Total annual volume of irrigation supply into the 3-D boundaries of the command area	*Total annual value of agricultural production:* Defined earlier *Total annual irrigated crop area:* Defined earlier
Output per unit water supply (US$/$m^3$)	Total annual value of agricultural production Total annual volume of water supply	*Total annual value of agricultural production:*. Defined earlier *Total annual volume of water supply:* Defined earlier
Output per unit of field ET (US$/$m^3$)	Total annual value of agricultural production Total annual volume of field ET	*Total annual value of agricultural production:* Defined above *Total annual volume of field ET:* Defined earlier

ENVIRONMENTAL PERFORMANCE INDICATORS

Indicator	Definition	Data specifications
Water quality: Average salinity of the irrigation supply (dS/m).	Salinity (electrical conductivity) of the irrigation supply.	Weighted (by volume) value, using monthly data. Should include both surface and groundwater supplies.
Water quality: Average salinity of the drainage water (dS/m).	Salinity (electrical conductivity) of the drainage water that leaves the command area.	Weighted (by volume) value, using monthly data.
Water quality: Average BOD of the irrigation supply (mgm/liter)	Biological load of the irrigation supply expressed as Biochemical Oxygen Demand (BOD)	Weighted (by volume) value, using monthly data. Should include both surface and groundwater supplies.
Water quality: Average BOD of the drainage water. (mgm/liter)	Biological load of the drainage water expressed as Biochemical Oxygen Demand (BOD)	Weighted (by volume) value, using monthly data.
Water quality: Average COD of the irrigation water (mgm/liter).	Chemical load of the irrigation supply expressed as Chemical Oxygen Demand (COD).	Weighted (by volume) value, using monthly data. Should include both surface and groundwater supplies.
Water quality: Average COD of the drainage water (mgm/liter).	Chemical load of the drainage water expressed as Chemical Oxygen Demand (COD).	Weighted (by volume) value, using monthly data.
Average depth to shallow water table (m)	Average annual depth of the shallow water table calculated from water table observations over the irrigation area.	This is an average value for the area of high water table.
Change in shallow water table depth over time (m) (+ indicates up)	Change in shallow water table depth over the last five years.	This is an average value for the area of high water table.

How to Interpret RAP Results

The RAP, by itself, is only a diagnostic tool. It allows a qualified evaluator to systematically examine the irrigation project to determine

1. External Indicators, and
2. Internal Indicators

The External Indicators will give an indication if it is possible to conserve water and enhance the environment through improved water management. The Internal Indicators give a detailed perspective of how the system is actually operated, and the water delivery service that is provided at all levels.

The interpretation of the results requires one or more irrigation specialists who clearly understand the options for modernization. Without a thorough knowledge of these options, the recommendations can be ineffective, to say the least.

Here are basic rules:

1. In almost all projects, modernization requires both hardware and management changes.

2. In general, it is quite possible to provide high levels of water delivery service to turnouts, without good water control, if the system is very inefficient and there is a very abundant supply of water. However, if the system must also be efficient, the only way to provide good water delivery service is to have excellent control of the water.

3. In almost all projects, water delivery service needs to be improved in order to meet the basic objectives of lower labor costs, less spill, improved crop yields, and less environmental damage. The RAP process allows the evaluator to target the appropriate level(s) on which to begin modernization.

4. In general, there are many very simple changes that can be made in operational procedures, and numerous others that only require a moderate investment in capital for hardware changes.

5. All changes must be accompanied by quality control and excellent training.

6. One must clearly understand the difference between Command Area Irrigation Efficiency and Field Irrigation Efficiency. In projects without internal recirculation, the Command Area Irrigation Efficiency is generally lower than the Field Irrigation Efficiency. But in projects with internal recirculation of water, the Command Area IE may be greater than the Field IE.

   The Command Area IE Benchmarking indicator combines many of the previous indicators into a single indicator value.

      Command area IE =

$$\frac{\text{Crop ET - Effective precipitation + Leaching irrig. water needed}}{\text{Surface irrigation water into the project + Net groundwater pumping}} \times 100$$

This expression of irrigation efficiency does not conform to the precise requirements defined in the ASCE document (Burt et al., 1997), but it is close enough to give a reasonable estimate of the command area IE.

A command area irrigation efficiency of 100% is impossible. In general, efficiencies greater than 60% require internal recirculation of losses – either as surface water recirculation or from groundwater pumping, or both.

In short, improvement of command area irrigation efficiency can be done in one of two ways:

1. Reduce first-time losses. These losses occur in two areas:
   a. Conveyance losses. These include
      - spillage from canals and pipelines
      - seepage from canals
      - phreatophtye water consumption
   b. Field losses. These include
      - conveyance losses in field channels
      - surface runoff from fields
      - deep percolation in fields, caused by
        * standing water in rice fields
        * non-uniformity of irrigation water application
        * excess duration of irrigation water application

   There is considerable merit in reducing first-time losses, because these can directly affect required canal capacity, fertilizer loss, pesticide losses, local water logging, etc. In most projects, seepage from canals is targeted, although often other components of first-time losses are more important and cause greater damage to the environment.
2. Recirculate first-time losses. Recirculation options include:
   a. Surface recirculation. Surface drains, creeks, and rivers pick up first time losses that originated as
      - seepage or deep percolation that returns to these creeks from a high water table.
      - surface runoff from fields
      - spillage from canals.
   b. Pumping from the groundwater. This recirculates first time losses that originated as
      - seepage
      - field deep percolation.

In some cases, recirculation is the least expensive and quickest option for improving project irrigation efficiencies.

A very common mistake in modernization is the elimination of first-time losses with the belief that this will improve project irrigation efficiencies…..even though those first time losses may already be recirculated within the project. If this is the case, there may not be any true water conservation.

However, other benefits can be obtained from the elimination of first-time losses such as:
- easier operation of the distribution system from lining
- better crop yields through better first-time water management
- less contamination of water due to fertilizers and pesticides.

At the beginning of the RAP Input sheets, the RAP user is asked to provide an estimates of field irrigation efficiency for rice and other crops. These estimates should account for all conveyance losses, field deep percolation, and surface runoff downstream of the delivery point from the project authorities.

But in "14. World Bank BMTI Indicators", a better estimate of Field Irrigation IE is given – based on a water balance of the project. One should compare this value against the stated value in Worksheet 1, to see if the stated value corresponds to the water balance values. In general, the water balance values are much closer to the truth.

How to use Field IE values

1. If the Field Irrigation Efficiency is low, one must not necessarily conclude that the farmers need better education on how to irrigate properly. In many projects, such training is worthless because project authorities dictate the schedule and amounts of water delivery, and the farmers have almost no choice in the matter.

   Low field irrigation efficiencies are typically an indication of a water delivery system that is unreliable, inequitable, and/or inflexible. Generally, the water delivery system must be improved before significant field efficiency improvement can take place.

   That said, there is one practice that can be implemented immediately without changing the water delivery system. That is land grading. Most of the world's irrigation projects use surface irrigation, and good land grading is important for good in-field distribution uniformity of water.

2. If

   Project IE > Field IE,

   Then there is considerable recirculation within the project.

3. The Project Irrigation Efficiency is the key indicator as to whether there is an opportunity to conserve water. Field Irrigation Efficiency gives no indication of this, by itself, because much of the field losses are often re-circulated.

4. "Water Conservation" in a hydrologic basin (as opposed to a specific irrigation project) can only be achieves if one of the following occurs:
   - Water flows to salt sinks (ocean, localized salty groundwater) is eliminated
   - Excess ET is reduced (weed and phreatophtye and drain ET is reduced)

5. Good water management, even if it does not conserve water in the basin, has appreciable benefits, including:
   - Improving downstream water quality.
   - Improving the TIMING of water usage
   - Reducing the flow rate requirements into a project.
   - Reduction of pumping (sometimes)
   - Improving crop yields through better timing of applications and less fertilizer leaching.
   - Improving the quality and quantity of flows in rivers and streams immediately downstream of irrigation diversion points.

Summary of the Interpretation Process

In general, the process of interpretation is as follows:

1. Field irrigation efficiencies are examined. Good field efficiencies depend upon receiving good water delivery service at the field.

2. Project irrigation efficiencies are examined. It is very common for irrigation project personnel to want higher flow rates into the project, although the inefficiencies may be quite high. An important alternative to increasing the water supply is to improve efficiencies.

3. Conveyance efficiencies are noted, and compared against field irrigation efficiencies. Both of these are considered in light of any recirculation (groundwater or surface) that may occur. The comparison helps to determine where efforts might be made.

4. The attributes of water delivery service are examined for each level.

5. The appropriateness of hardware and operator instruction is reviewed.

6. The existence of recirculation systems is noted. In many project, installing surface water recirculation systems in strategic areas is a very simple way to improve performance and water delivery service.

7. Where employees spend their time is an important indication of where changes can be made. For example, in many projects there is a large staff of hydrographers who continually take current meter readings at many locations in the main canals. In general, this inaccurate (due to the inherent nature of unsteady flows and point-in-time measurements) work can be completely eliminated if a new strategy for water delivery is adopted.

With modernization, some actions can be taken in parallel with others, but some actions require a foundation. For example, automation with electronic PLCs (Programmable Logic Controllers) first requires excellent access to sites, excellent communications, and a strong infrastructure for electronic troubleshooting and repairs. They also require a project that has an excellent maintenance record. In other words, PLC automation requires a substantial foundation that is often lacking in irrigation projects….and PLC implementation without that foundation is almost guaranteed to fail.

Typically, the key steps for modernization are:

1. Eliminate the discrepancy between "actual" and "stated" service. If project managers refuse to accept reality, it is best to spend time and money on other projects.
2. All levels of staff must understand and adopt the "service mentality". Of course, this is not done overnight, but modernization concepts are rooted in this mentality. Without having it, attempts to modernize a project will typically have minimal benefit.
3. Examine instructions that are given to operators, and modify them if needed. A classic example is many Asian projects in which the objective of cross regulators is to maintain an upstream water level, but the gate operators must move the cross regulators in strict accordance with instructions (of specific gate movements) from the office – based on computer programs or spreadsheets. A simple check in the field will show that water levels are not maintained properly. The instructions for the operators must be changed, and they are very simple: "Maintain the upstream water level within a specified tolerance of a defined target". The author has never found an operator who is incapable of determining how much to move the cross regulators to achieve this goal.
4. The first 3 items are the easiest, but they may also be the most difficult with some senior staff. If the first 3 items cannot be achieved, it is best to either walk away from a project, or else fire the senior staff. Of course, changes in the first 3 items may take some training, study tours, and deep conversations.
5. The next steps, more or less in order of sequence, are to improve the following areas:
   a. Understanding of what actually happens in the system. An expert can quickly evaluate a project and because of his/her background, almost immediately understand cause/effect relationships and the probable level of service. The operators and supervisors often do not see things the same way. It is very helpful to install simple dataloggers and water level sensors at key locations to record spills, flow rate fluctuations, and water level fluctuations. This is almost always an eye-opener for operators who can only visit a location once per day.
   b. Communications at all levels. This starts with human-human communications – often with radios.
   c. Mobility of staff. In general, a small yet mobile staff is much more efficient than a large, immobile staff. This is because a small mobile staff is not responsible for just one or two structures, but must understand how various structures and actions will impact other areas. Mobility may be improved with better roads, motorcycles, trucks, etc.
   d. Flow rate control and measurement at key bifurcation points. Note that "measurement" and "control" are not the same. Both are needed. There are many

combinations of structures and techniques that provide rapid and accurate control and measurement of flow rates. This is typically a weak area for many irrigation projects.

e. Existence of recirculation points or buffer reservoirs in the main canal system. "Loose" water control may be very adequate in the main system – as long as there exists a place to re-regulate about 70% of the way down a canal.
f. Improved water level control throughout the project. The flow rate control and measurement (item "d") only pertain to the heads of canals and pipelines. Downstream of the head, it is important to easily maintain fairly constant water levels so that turnout flow rates do not change with time, and so that the canal banks are not damaged. With the proper types of structures, this is easy to do without much human effort.
g. Re-organization of procedures for ordering and dispersing water. In most modern projects, one group is responsible for operating the main canal; another is responsible for the second level, and so on. Each group then has a very specific service objective. If a main canal is broken into "zones" with different offices controlling different "zones", there is almost always conflict between the zones. Re-organization of the operators is typically necessary. Also, the complete procedure for receiving real-time information from the field and responding quickly to requests must typically be revamped for most projects.
h. Remote monitoring of strategic locations. Such locations are typically buffer reservoirs, drains, and tail ends of canals.
i. Remote manual control of flow rates at strategic locations. These are the heads of the main canal, and heads of major off takes (turnouts) from the main canal.
j. Provision for spill, and the recapture of that spill, from the ends of all small canals.

What may surprise some readers is the complete lack of discussion of canal lining and maintenance equipment. There is no doubt that maintenance equipment must be adequate. Canal lining can reduce maintenance and seepage. But these topics have been discussed for many decades, and the billions of dollars that have been spent on canal lining have generally not brought about modernization. This is because modernization is not just a single action. The items a-j represent a departure from traditional thinking of "concrete civil engineers" and focus on operations.

Another missing item is a discussion about downstream control and sophisticated canal control algorithms. This is because an irrigation project must walk very well before it runs, and these technologies might be considered as "high risk". Although the author spends a considerable amount of professional time on these two subjects in actual applications, sophisticated controls are only selected after other options have been ruled out…..and never before an adequate support infrastructure exists. There is just no magical pill for modernization and improved irrigation performance, and simple options often provide excellent results.

It is good to listen to the operators and try to detect a few things that give them a tremendous amount of grief. It is sometimes possible to quickly solve some of these problems. By solving these problems for the operators, they will become advocates of further modernization efforts.

Conclusions

The RAP, when conducted and analyzed by a qualified irrigation engineer, provides indicators that explain results and processes of an irrigation project. Many of these indicators can be used for Benchmarking purposes, allowing for a comparison between projects and pre/post modernization performance. The RAP provides, in a very short period of time of only a few weeks, sufficient information to target key action items for modernization. It therefore serves as a valuable tool for countries to prioritize investments to different projects, and to prioritize specific actions within individual irrigation projects.

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